P. O. BOX 555

OWEN 6-4710

AEROPROJECTS INCORPORATED
310 EAST ROSEDALE AVENUE, WEST CHESTER, PENNSYLVANIA



November 16, 1962

Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.

Qualified requesters may obtain copies of this report from ASTIA.

Attention: RRMA-231

Via: Inspector of Naval Material
10 North 8th Street
Reading, Pennsylvania



Subject: ULTRASONIC WELDING OF REFRACTORY METALS
Progress Report No. 9
For the Period 1 June through 31 July, 1962
Navy Contract No. NOw 61-0410-c

Gentlemen:

During this report period, D-31 alloy (10 Mo-10Ti-Cb) was selected for ultrasonic welding study. Although the alloy's metallurgical characteristics indicate potentially good weldability, considerable difficulty has been encountered heretofore* in obtaining crack-free, consistant-strength joints.

To support our studies, a review of existent literature covering this type of alloy has been made. Despite the fact that little published data exist on columbium and its alloys, our investigative consensus indicates that material quality in general, and its contamination in particular, may be controlling factors in previously encountered ultrasonic welding difficulty.

Further studies are being made of D-31. It is anticipated that they will provide a deeper understanding of the problems involved, and will supply, therefore, the basis for development of suitable solutions.

Some of the data contained in this report has been deduced from work performed by this contractor for the United States Air Force**.



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* Progress Reports No. 2, 3, 5.

** Development of Ultrasonic Welding Equipment for Refractory Metals. Contract AF 33(600)-43026, ASD Project No. 7-888, Fabrication Branch Manufacturing Technology Laboratory. AFSC Aeronautical Systems Division, United States Air Force.

WELDING D-31

Table I gives the results of comparative studies of the weldability of 0.005-inch D-31. Materials designated "old" refer to D-31 procured early in 1961. Those marked "new" refer to purchases made in 1962. The tensile-shear data have been analyzed statistically in a manner convenient to a designer.

An examination of Table I and Figures 1 through 7 leads to the following preliminary conclusions regarding the weldability of 0.005-inch D-31 alloy foil:

a. "New" D-31 possesses good ultrasonic weldability. Crack-free welds with good tensile-shear consistency can be made, at least with the foil size under study. Figures 3 and 6, for instance, show weld interfaces with complete bonding and lack of surface-film residues.

b. Good ultrasonic welds can be attained over a considerable power range: 850 watts with the 0.25-inch spherical sonotrode-tip radius (Study No. 2, Table I) to 1600 watts with the 0.75-inch tip radius (Study No. 10, Table I; Figures 5, 6). Weld strengths consistency is good, standard deviation is low.

c. The material is somewhat sensitive to clamping force. For example, an increase in the clamping force of 50 pounds, (650 to 700 lbs) or approximately 8 percent (Studies No. 4, 6, Table I) improved weld consistency so that the expected minimum ($\bar{x}-3\sigma$) tensile-shear increased from 12 pounds to 53 pounds, and standard deviation ($\sigma$) decreased from 17 pounds to 8.5 pounds, respectively.

d. D-31 seems to be sensitive to tip surface condition and to surface cleanliness (Figure 7).

e. Although good welds may be made with low power and low clamping force (as obtained from the threshold curves) (Study No. 2, Table I), better consistency and higher-strength levels are obtained with higher power and higher clamping force (Studies No. 6, 10, Table I; Figures 5, 6).

f. Welding slightly below minimum clamping force yields poor results (Studies No. 7, 8, Table I; Figures 2, 4; Table II). Some welds made with low clamping force are good (Figures 2, 3) but strength inconsistency exists, with the majority of specimens showing a lack of bonding. Little cracking has been observed. Cracks would be anticipated with the use of low clamping force and the lower-quality material which the specimen stock in Study 7, Table I apparently is.

g. The most suitable sonotrode-tip radius appears to be 0.5 inch (100t) (Study 6, Table I; Figure 1). The 0.25-inch tip radius could be used, despite resultant high deformation, or the 0.75-inch tip radius (100t). However, higher power and clamping force are required with larger tip radius (Study 10, Table I; Figures 5, 6).

h. Material quality appears to exert a paramount controlling effect on weld quality, strength level, and consistency (Studies 1-2, 3-4, 5-6, 7-8, 9-10, Table I; Progress Report No. 5, p. 4). Material procured in 1962 displayed considerably superior weldability over that procured early in 1961. The processing history of the material is not available, however, and the producer is apparently unwilling to reveal it. Hence, any definite conclusions may not be drawn from the limited studies.

## INSPECTION TECHNIQUES

Further investigations have been made into developing a reliable, inexpensive method for weld-quality inspection*. Two possibilities for such inspection have been determined: One is by use of an infra-red radiometer**, and the other by use of an "Ultrasonic Image Converter"***. Since the latter method is currently being reinvestigated by the Armour Research Foundation of the Illinois Institute of Technology under the sponsorship of the Air Force and the Bureau of Ships, additional information is being requested from Armour.

## FUTURE WORK

Future work will be concentrated on attempting to establish a correlation between the structures and microhardness of D-31 as investigated, and ultrasonic weld quality and strength. In addition, studies continue into the ultrasonic weldability of Mo-0.5Ti alloy. The results of such studies will be covered in the next Progress Report.

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* Progress Reports No. 4 through 8.
** Barnes Engineering Co., Stamford, Conn.
***"Sound Tube Pictures", The Iron Age, Vol. 190, No. 11, Sept. 13, 1962, pp. 171-172.

Very truly yours,

Harold L. McKaig, Jr.
Manager, Advanced Projects

HLM:ss

Table I

SUMMARY OF COMPARATIVE TENSILE-SHEAR STRENGTH DATA
OF ULTRASONICALLY WELDED 0.005-INCH D-31 ALLOY FOIL
WITH DIFFERENT WELDING PARAMETERS

Note: All tabs were degreased only by washing in acetone. Additional abrading with No. 400 Emery (No. 12) yielded inferior results.

| No. | Gage (inch) | Stock | Sonotrode Tip Radius, (inch) | Welding Parameters: Power, watts | Clamping Force (pound) | Time Interval, (second) | Tensile-Shear Data, lbs[1]: $\bar{x}$[2] | $\sigma$[3] | $\bar{x}-3\sigma$[4] | N[5] | Figure No. | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.005 | Old | 0.25 | 850 | 400 | 0.75 | 55 | 15.7 | 8 | 30 | | |
| 2 | 0.005 | New | 0.25 | 850 | 400 | 0.75 | 70 | 13.5 | 29 | 10 | | |
| 3 | 0.005 | Old | 0.5 | 1400 | 650 | 0.75 | 48 | 76 | -28 | 11 | | |
| 4 | 0.005 | New | 0.5 | 1400 | 650 | 0.75 | 63 | 17 | 12 | 11 | 1 | |
| 5 | 0.005 | Old | 0.5 | 1400 | 700 | 0.75 | 63 | 11.8 | 28 | 13 | | |
| 6 | 0.005 | New | 0.5 | 1400 | 700 | 0.75 | 79 | 8.5 | 53 | 10 | | |
| 7 | 0.005 | Old | 0.75 | 750 | 300 | 0.5 | 50 | 18.9 | -7 | 20 | 2,3,4 | |
| 8 | 0.005 | New | 0.75 | 750 | 300 | 0.5 | 64 | 21.1 | 1 | 10 | | |
| 9 | 0.005 | Old | 0.75 | 1600 | 700 | 0.75 | 72 | 20.3 | 11 | 21 | | |
| 10 | 0.005 | New | 0.75 | 1600 | 650 | 0.75 | 107 | 13.6 | 66.2 | 14 | 5,6,7 | |
| 11 | 0.010 | Old | 1.0 | 2000 | 750 | 0.75 | 273 | 22.6 | 206 | 13 | | |
| 12 | 0.010 | Old | 1.0 | 2000 | 750 | 0.75 | 135 | 78 | -99 | 6 | | Abraded |
| 13 | 0.010 | Old | 1.0 | 3200 | 900 | 0.75 | 132 | 25 | 57 | 10 | | Studies made on tabs sectioned from different strips |
| 14 | 0.010 | Old | 1.0 | 3200 | 1000 | 0.75 | 119 | 16 | 75 | 10 | | |
| 15 | 0.010 | Old | 1.0 | 3200 | 1000 | 0.75 | 129 | 43 | 0 | 20 | | |
| 16 | 0.015 | Old | 1.0 | 2800 | 800 | 0.75 | 244.7 | 46.9 | 104 | 16 | | |
| 17 | 0.015 | Old | 1.0 | 3200 | 1100 | 0.75 | 189.8 | 53.3 | 29.9 | 20 | | |

1) Statistically analyzed
2) $\bar{x}$ = Expected average
3) $\sigma$ = Standard deviation
4) $\bar{x}-3\sigma$ = Expected minimum
5) N = Number of population

Table II

SUMMARY OF METALLURGICAL STUDIES OF ULTRASONICALLY SPOTWELDED 0.005 INCH D-31 WITH THE CLAMPING FORCE BELOW THAT INDICATED BY THE THRESHOLD STUDIES
(See Study No. 7, Table I)

| Spec. No. | Bond Quality | Cracking | Figure No. |
|---|---|---|---|
| 2 | Good | None | 2,3 |
| 4 | Satisfactory | None | |
| 6 | Poor | None | |
| 8 | Very Poor | None | |
| 10 | Good | None | |
| 12 | Satisfactory | Edge micro-cracks | 4 |
| 14 | No weld | None | |
| 16 | No weld | None | |
| 18 | No weld | None | |

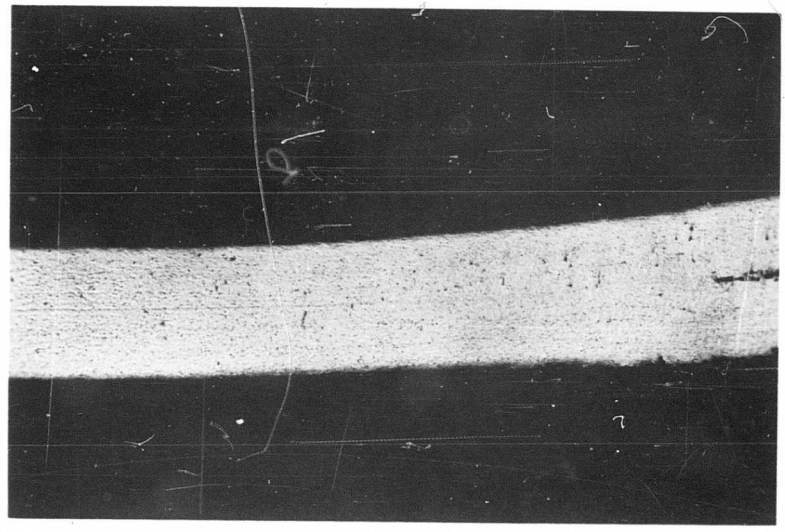

Figure 1

ULTRASONIC SPOTWELD OF 0.005-INCH D-31 ALLOY FOIL (NEW STOCK) MADE WITH 0.5-INCH SPHERICAL-TIP RADIUS

Welding Parameters: 1400/650/0.75

Etchant: Lactic Acid 50 parts
$HNO_3$ 30 parts
HF 10 parts
in $H_2O$

Magnification: 100X

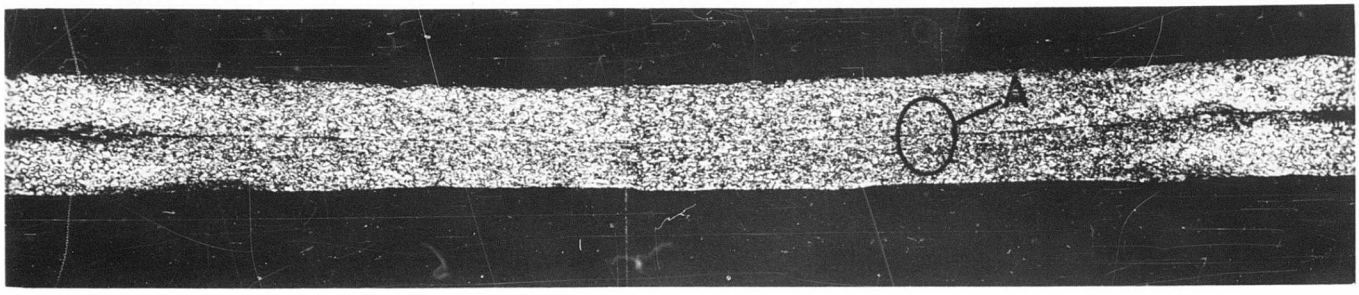


Figure 2

ULTRASONIC SPOTWELD OF 0.005-INCH D-31 ALLOY
FOIL (OLD STOCK) MADE WITH 0.75-INCH SPHERICAL-TIP RADIUS
WITH LOW CLAMPING FORCE

Welding Parameters: 750/300/0.5

Etchant: As in Figure 1

Magnification: 100X

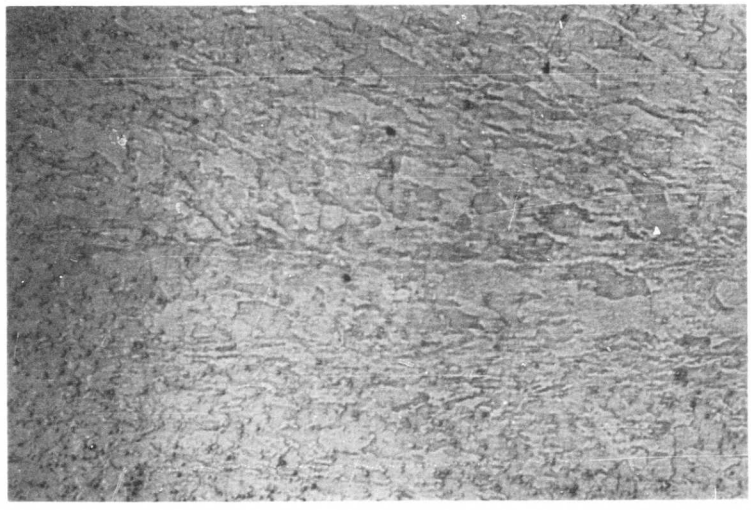

Figure 3

DETAIL A FROM FIGURE 2

Magnification: 500X

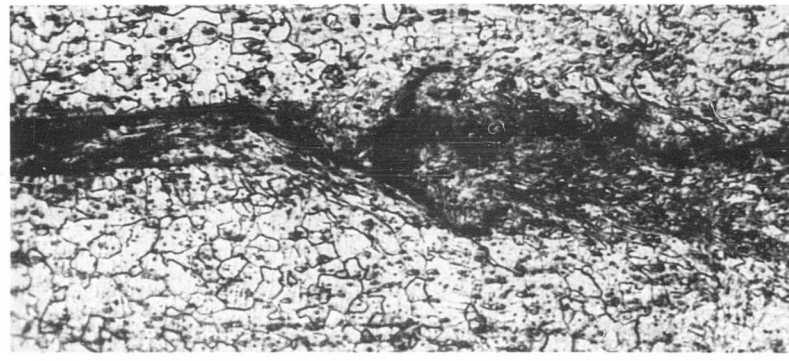

Figure 4

ULTRASONIC SPOTWELD OF 0.005-INCH D-31 ALLOY FOIL (OLD STOCK) MADE IDENTICALLY TO FIGURE 2, SHOWING EDGE CRACKS

Etchant: Same as Figure 1
Magnification: 500X

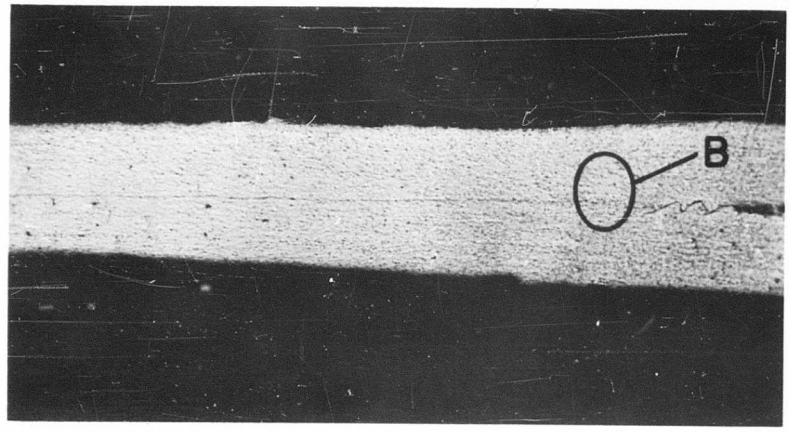


Figure 5

ULTRASONIC SPOTWELD OF 0.005-INCH D-31 ALLOY FOIL (NEW STOCK)
MADE WITH 0.75-INCH SPHERICAL-RADIUS TIP

Welding Parameters: 1600/650/0.75

Etchant: Same as Figure 1

Magnification: 100X

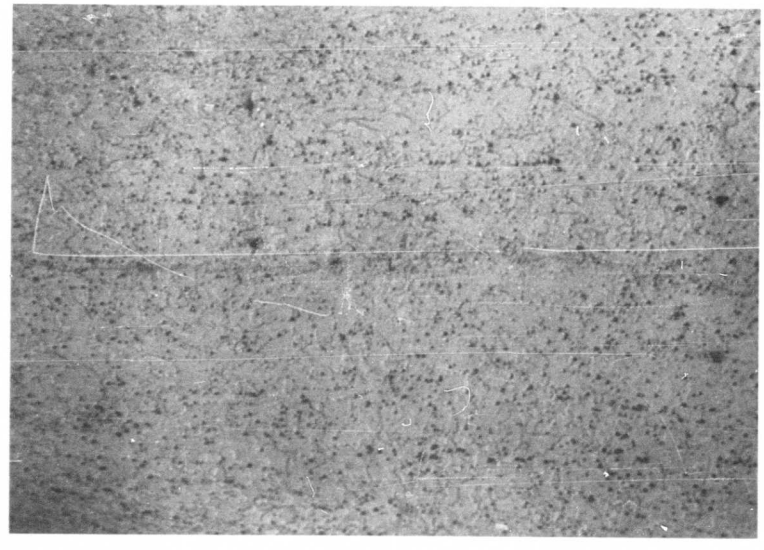

Figure 6

DETAIL B FROM FIGURE 5

Magnification: 500X

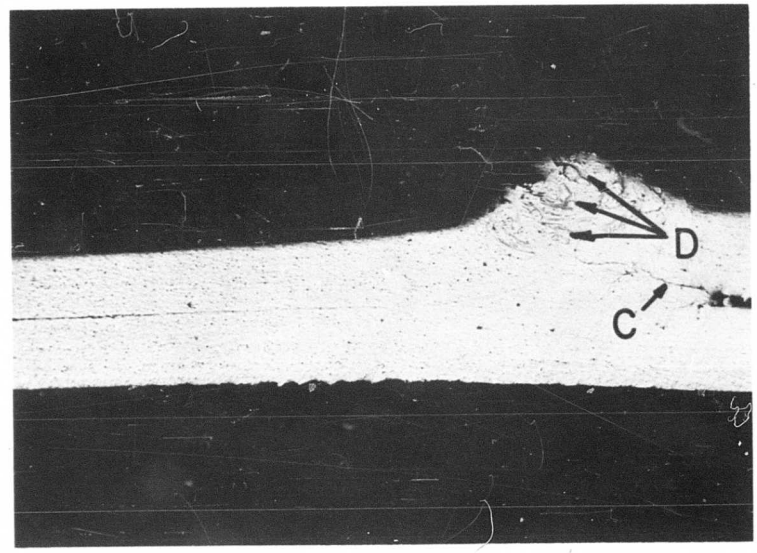


Figure 7

SAME AS IN FIGURE 5 WITH A MICROCRACK (C)
ON THE OUTSIDE OF THE PERIPHERY OF THE WELD WHERE METAL
WAS PILED-UP WITH FOREIGN MATERIAL PARTICLES (D)
ON THE SONOTRODE-WORK INTERFACE

Etchant: Same as Figure 1
Magnification: 100X

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